

## REPORT DOCUMENTATION PAGE

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14. ABSTRACT We have completed work in the areas of physics-based illumination modeling, invariant 3D object recognition, and spectral/spatial modeling. The illumination models consider over 7,000 measured visible through short-wave infrared spectra I irradiance functions. We developed compact representations for the spectra, and used the representations to establish new results for invariant material discriminability. We have also developed models and algorithms for the recognition of 3D objects in unknown illumination conditions. The DIRSIG image generation code was used to build invariant spectral/spatial 3D object models. The algorithms have been applied to a series of hyperspectral images with varying spatial resolution. We have also developed a multi-scale opponent representation to hyperspectral texture based on Gabor filter outputs. We have applied this representation to hyperspectral texture classification in AVIRIS images. We have also developed a more detailed hyperspectral spatial structure model using multiband correlation functions.					
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**Title:** Combining Physical and Statistical Models for Recognition in Hyperspectral Images  
**Principal Investigator:** Glenn Healey  
**Department:** Electrical and Computer Engineering  
**Institution:** University of California, Irvine 92697  
**Phone:** (949) 824-7104  
**E-mail:** healey@ece.uci.edu  
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## 1 Objectives

We consider the problem of recognizing objects in outdoor images acquired under unknown conditions when only a few pixels are available on the object. The development of this capability would enable the recognition of small or partially obscured objects at large distances thereby enhancing the performance of systems for many applications such as wide-area search and image registration. A recognition system that operates in an uncontrolled outdoor environment must overcome several substantial challenges. The appearance of an object in an outdoor scene is highly variable due to spatial and temporal variation in the illumination and atmospheric conditions. Also, in images of distant or obscured objects, modeled object surfaces may appear at subpixel scale therefore reducing the usefulness of geometric features.

## 2 Status of Effort

We have completed work in the areas of physics-based illumination modeling, invariant 3D object recognition, and spectral/spatial modeling. The illumination models consider over 7,000 measured visible through short-wave infrared spectral irradiance functions. We developed compact representations for the spectra and used the representations to establish new results for invariant material discriminability. We have also developed models and algorithms for the recognition of 3D objects in unknown illumination conditions. The DIRSIG image generation code was used to build invariant spectral/spatial 3D object models. The algorithms have been applied to a series of hyperspectral images with varying spatial resolution. We have also developed a multiscale opponent representation for hyperspectral texture based on Gabor filter outputs. We have applied this representation to hyperspectral texture classification in AVIRIS images. We have also developed a more detailed hyperspectral spatial structure model using multiband correlation functions. This model allows the recognition of 3D structures based on a statistical model in the presence of changes in the environmental conditions.

### 3 Accomplishments

In the area of illumination modeling, we considered the largest set of outdoor illumination spectra that have been analyzed to date. We extended the traditional analysis to consider the short-wave infrared spectral range. We showed that the illumination spectra can be accurately modeled by a 3-parameter model over the visible wavelengths and by an 8-parameter model over the visible through short-wave infrared wavelengths. The analysis includes a comparison of the data with the results of previous studies and a comparison of the data with spectra generated by the MODTRAN 4.0 modeling system. We also analyzed how the illumination variability in the data affects the performance of algorithms that used hyperspectral reflected radiance vectors for material identification. We showed that for 223 materials over 7,258 illumination conditions, a 10-dimensional model can be used to identify correctly over 99% of the reflected radiance spectra.

We have also developed new models and algorithms for the recognition of distant 3D objects in visible through short-wave infrared hyperspectral images of outdoor scenes acquired under unknown conditions. Objects are represented using subspace models that capture environmental variability and object pose variability. The DIRSIG image generation software is used during model building. The subspace models are designed to account for spectral mixing since we consider scales at which multiple materials mix in a pixel. We showed using DIRSIG imagery that complex 3D objects can be recognized under unknown conditions at low false alarm rates even when the object occupies significantly less than one pixel. The experiments consider both desert and urban environments with substantial clutter. The orthogonal projection ratio was developed as a new tool for 3D object recognition.

We have developed feature subspaces for texture modeling and recognition in hyperspectral imagery using unichrome and opponent features computed from Gabor filter outputs. The opponent features are motivated by opponent processes in human vision. These features capture multiscale spatial information within and between spectral bands. Using an AVIRIS data set, we demonstrated the discriminatory power of optimized feature sets that include opponent features for texture recognition. We have shown that using both unichrome and opponent features significantly improves the performance of texture classification over using the same number of unichrome features.

Detailed nonparametric models can also be used for texture modeling and recognition. We have developed new algorithms based on multiband correlation models for the recognition of hyperspectral textures in three dimensions. The bidirectional texture function describes the appearance of a textured surface as a function of the illumination and viewing directions. We used the DIRSIG model to generate a set of hyperspectral images over ranges of illumination and viewing angles in the 0.4-2.5 micron spectral region. We showed that the new models and algorithms can successfully recognize 3D textures under unknown illumination angle.

### 4 Personnel Supported

Glenn Healey, P.I.

Zhihong Pan, Ph.D. student researcher  
Miaohong Shi, Ph.D. student researcher  
Yong Liu, Ph.D. student researcher

## 5 Publications

### Journal Publications

- [1] B. Thai and G. Healey, "Invariant Subpixel Material Detection in Hyperspectral Imagery," *IEEE Transactions on Geoscience and Remote Sensing*, 40(3), 599-608, 2002.
- [2] Z. Pan and G. Healey, "Global spectral irradiance variability and material discrimination at Boulder, Colorado," *Journal of the Optical Society of America*, 20(3), 513-521, 2003
- [3] M. Shi and G. Healey, "Hyperspectral texture recognition using a multiscale opponent representation," *IEEE Transactions on Geoscience and Remote Sensing*, 41(5), 1090-1095, 2003
- [4] M. Shi and G. Healey, "Using multiband correlation models for the invariant recognition of 3D hyperspectral textures," *IEEE Transactions on Geoscience and Remote Sensing*, under revision.

### Reviewed Conference Publications

- [1] Z. Pan and G. Healey, "Recognizing 3D objects in hyperspectral images under unknown conditions," SPIE Proceedings volume 4381, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VII, 559-569, 2001.
- [2] M. Shi and G. Healey, "Representing hyperspectral textures using opponent features," SPIE Proceedings volume 4725, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery VIII, 38-46, 2002.
- [3] M. Shi and G. Healey, "Applying opponent spectral features to AVIRIS imagery," NASA AVIRIS Earth Sciences workshop, 2002.
- [4] M. Shi and G. Healey, "Three-dimensional hyperspectral texture recognition using multi-band correlation models," SPIE Proceedings volume 5093, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery IX, 678-685, 2003.
- [5] Y. Liu and G. Healey, "Recognizing 3D objects in cluttered backgrounds," SPIE Proceedings volume 5093, Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery IX, 9-16, 2003.

## 6 Interactions/Transitions

### Conference Presentations

SPIE Aerosense conference on Multispectral, Hyperspectral, Ultraspectral Imagery, 2001  
SPIE Aerosense conference on Multispectral, Hyperspectral, Ultraspectral Imagery, 2002  
SPIE Aerosense conference on Multispectral, Hyperspectral, Ultraspectral Imagery, 2003

JPL AVIRIS workshop 2002

## **7 Patent Disclosures**

none

## **8 Honors**

Invited speaker at First UCI Research Review, 2002